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Harmonics Currents Cancelation by Three-Phase 4-wire Hybrid Active Power Filter with Split Capacitors and STF

Mohamed Muftah SaleemAbdusalam
(Electrical and computer Department, faculty of Engeneering-Alkhoms/ ElmergibUniversity, Libya)
Corresponding Author: Mohamed Muftah SaleemAbdusalam

Abstract: *The quality of electrical power is the major important goal of all researchers. In utility power system it has been observed that harmonics build a major role in reducing the quality power. These harmonics caused by nonlinear loads. Many consumers appliances demand quality power continuously for their operation. The performance of the end user equipment is heavily dependent on the quality of power supplied to it. This power is affected by various external and internal factors. They are like voltage and frequency variations, faults, outages etc. The solution to overcome these problems is to filter out these harmonics. For this purpose, there are many filters topologies are proposed and studied in the literature to eliminate harmonics currents. In this paper, three phase 4-wire hybrid filter is proposed with Self-Tuning-Filter (STF).in this paper, a hybrid power filter is proposed to solve problems of line harmonic currents and neutral line currents of three phase four wire power distribution system. The hybrid filter is three-arm power converter with split capacitors. This configuration uses a smaller number of power electronic switches to reduce the manufacturing cost. The use of STF in the control method can optimize the performance of this topology regarding to classical one. The proposed control strategy is simulated in MATLAB Simulink and the results are presented.*

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I. Introduction

To overcome the problems caused by harmonics, filters are used. There are different filter topologies present in the literature for this purpose. Passive filters consist of passive elements like- capacitor, inductor and resistor. These are widely used because of their low cost and ease of control. The passive filters also provide reactive power apart from filtering the harmonics. The performance of these filters is heavily dependent on the system impedance. These are again classified into two types- low pass and high pass [1]. At first passive filters are used but they are dependent heavily on the system parameters. They also have the problems of resonance with system impedance and are suitable for filtering out a particular frequency harmonic. Therefore, to overcome the problems of passive filters, active filters are used. These are used since 1970"s to compensate the reactive power, negative sequence currents.

The use of active power filters for power quality improvement is presented in many papers along with control strategies. It is found that the active filters are facing some drawbacks when employed for power quality improvement. They are (huge converter rating is required, huge size, increased losses).

Therefore, to overcome these drawbacks a hybrid power filter which is a combination of active and passive filters is proposed. Three-phase four-wire distribution power systems are widely used in office buildings, commercial complexes, manufacturing facilities and so on, to supply lower-level voltage. The active power filters aren't a new solution for thecompensation of harmonic pollution in power systems. We can distinguish two types of active filters, series and shunt.The shunt active power filter makes the compensation of harmonic currents and reactive power.

The application of active power filters (APF) for mitigating harmonic currents and compensating for reactive power of the nonlinear load was proposed more than decades ago. Since then, the theory and development of active filters have become very popular and have attracted much attention. The active filter appears to be a viable solution for controlling harmonics-associated problems.

Figure 1, shows a typical schematic diagram of a three-phase four-wire shunt active power filter (SAPF). In operation, the active filter injects equal but opposite distortion as well as absorbing or generating reactive power, thereby controlling the harmonics and compensating for reactive power of the connected load.

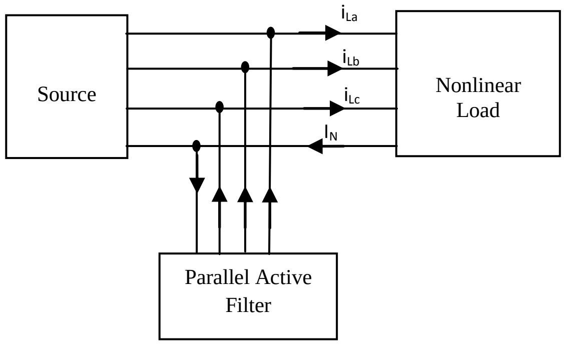


Figure 1. Three phase 4-wire shunt active power filter.

The control method used for this topology based on the theory of instantaneous power (p–q theory), in the α–β reference frame, which inspired the realization of three-phase active power filters. With this concept, unless used for harmonic cancellation, there is no need to use an energy-storage device in the active power filter implementation for reactive power compensation of the load. Since the p–q theory was introduced, many instantaneous power theory-based methods either in the 0– α–β or in the a–b–c reference frame have been proposed for the control strategies of the active power filter. For instance, the p–q theory requires transformation of both source voltages and load currents from the a–b–c reference frame to the α–β reference frame to determine the SAPF reference compensation currents in the three-phase three-wire system. For applications of the SAPF in a three phase four-wire system, extended the p–q theory to handle zero-sequence power compensation with a more complicated controller design.

Most control strategies of active power filter focus on the elimination of harmonic currents and reactive power compensation for the nonlinear load, while the source voltages can be either ideal or imbalanced and/or distorted. However, the issues related to how to plan the SAPF for different performance requirements to meet the harmonic current distortion limits and other constraints such as minimum power factor and current imbalance limits are rarely investigated [2–5].

Hybrid active power filters (HAPF) are developed to solve the problems of the passive power filter and the active filter. Generally, it is very important to compensate the dominant harmonics and thus Total Harmonic Distortion (THD) below 5% as specified in IEEE 519 harmonic standard. The hybrid filter consists of a passive filter and a power converter.Hybrid filters are based on the combination of active filters and passive filters. Such a combination with the passive filter makes it possible to significantly reduce the rating of the active filter.

The task of the active filter is not to compensate for harmonic currents produced by the thyristor rectifier, but to achieve "harmonic isolation" between the supply and the load As a result, no harmonic resonance occurs, and no harmonic current flows in the supply. In operation, the passive filter can reduce the capacity of the power converter, whereas the power converter is used to improve the filter characteristic of the passive filter [6].

Figure 2. present three-phase four-wire Hybrid Active Power Filter (HAPF) with split capacitors and new control method with self-tuning filter (STF) to simplify d–q–0 classical reference frame. It is configured by a three-arm bridge structure which permits to connect directly the neutral line of the utility between two DC capacitors located in the DC side of the power converter. Consequently, the power converter uses a smaller number of power electronic switches to reduce the manufacturing cost [6].

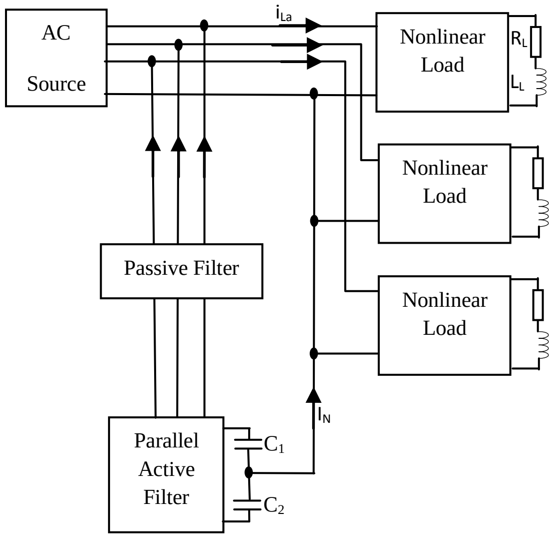


Figure 2. Three phase 4-wire hybrid active power filter with split capacitors.

II. Studied System and References Generation

The studied system in this paper is three phase four wire hybrid power filter. Shunt active power filter is used to generate compensation current in opposite phase. Power circuit for SAPF is proposed as an MOSFET based three-phase voltage source inverter with 2 DC storage capacitor for better compensation of non-linear loads [8-9]. Control scheme has two loops, feedback and feedforward loop for reference current generation and PI controller for dc voltage regulation.

The capacitors are designed to limit the dc voltage ripple to a specified value. The nonlinear load is a diode rectifier feeding (R, L) series load. The passive filter is a three-phase LC filter tuned for the 7th harmonic frequency, connected in series with an active filter without any transformer.

The control scheme applied is like that we used in [8] but here we take in account the neutral current in the system. The method used for the calculation of reference current based on d-q theory with STF which allows to maintain supply current waveform sinusoidal, identification of harmonic content and regulation of dc voltage.

The three-phase unit voltage (v_{sa}, v_{sb}, v_{sc}) are obtained from the supply voltages.
The three phase supply currents, i_{sa}, i_{sb} and i_{sc} are measured for the feedback loop and transformed into 0-α-β reference frame:

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = C \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \qquad (1)$$

$$C = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \qquad (2)$$

$i_N = i_{sa}+i_{sb}+i_{sc}$ (3)

$i_0 = 1/\sqrt{3}*(i_{sa}+i_{sb}+i_{sc}) = 1/\sqrt{3}*i_N$ (4)

A STF is introduced in feedback loop in order to extracts the AC components directly from the current in the α-β axis. By PLL we can generate the signals sin(θ) and cos(θ) in order to apply d-q theory.

$$\begin{bmatrix} id \\ iq \\ i_0 \end{bmatrix} = \begin{bmatrix} 0 & sin(\theta) & -cos(\theta) \\ 0 & cos & sin(\theta) \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (5)$$

The resulting signals are the AC components which correspond to the harmonic components of i_{sa}, i_{sb} and i_{sc} in the stationary reference frame. Then, after computation based on d-q inverse transformation, we obtained the three-phase harmonic reference currents.

$$\begin{bmatrix} i_{sHa} \\ i_{sHb} \\ i_{sHc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{ref\alpha} \\ i_{ref\beta} \\ i_{ref\,0} \end{bmatrix} \quad (6)$$

Each harmonic current i_{sH} is amplified by a gain K in order to produce the three ac voltage references of the feedback loop, given by:

$$V_{Sh}^{*} = i_{Sh} \times K \qquad (7)$$

The feedforward loop is applied to the most dominant 5^{th} harmonic current component to improve filtering characteristics of the hybrid filter. The principal of this feedforward control is presented clearly in our paper [8].

When applying the α-β inverse transformation in feedforward loop, we obtained the three-phase feedforward voltage references. Those references are added to the output voltage references established by the feedback loop to define the total voltage references for the active filter. Finally, each voltage reference is compared with a triangular waveform to generate the switching signals for the six MOSFETs.

III. DC Bus Voltage Control

A dc bus controller is required to regulate the dc bus voltage V_{dc} and to compensate the inverter losses. The measured dc bus voltage V_{dc} is compared with its reference value V^{*}_{dc}. The resulting error is applied to a Proportional Integral (PI) controller.

The Proportional value determines the reaction to the current error; the Integral determines the reaction based on the sum of recent errors. The transfer function can be represented as:

$H(S) = k_p + k_i/s$ (8)

Where, kp is the proportional constant that determines the dynamic response of the DC-bus voltage control, and k_i is the integration constant that determines it's settling time.

If k_p and k^i are large, the DC-bus voltage regulation is dominant, and the steady state DC bus voltage error is low. On the hand, if k_p and k_i are small, the real power unbalance gives little effect to the transient performance. Therefore, the proper selection of k_p and k_i is essentially important to satisfy above mentioned two control performances [5].

The proportional and integral gains are set to $0.2\Omega^{-1}$and 20 $\Omega^{-1}s^{-1}$ respectively.

IV. Simulation Results

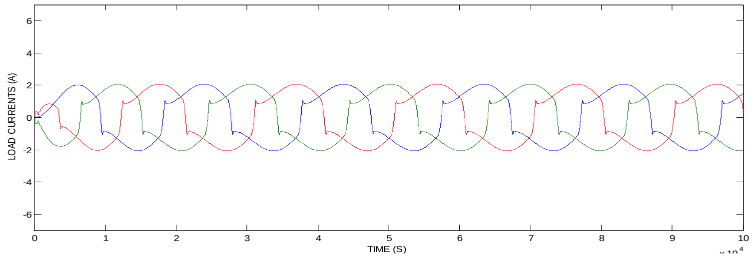
The parameters of the studied system are: Load resistance $R_L = 0.2\ \Omega$, Load inductance $L_L = 12.5$ mH, passive filter (L_f=20mH, C_f=57.6µF), Supply line parameters $R_s = 0.001\ \Omega$, $L_s = 0.15$ mH, resistance $R_d = 160\ \Omega$, inductance $L_d = 0.3$ H, inverter DC bus capacitor is of 1500µF each, source voltage = 480V, System frequency=60Hz, switching frequency = 10 kHz, PI controller parameters are $K_i = 20\ \Omega^{-1}s^{-1}$, $K_p = 0.2\Omega^{-1}$.The THD of the non-linear load i_L is equal to 22.5% because of the large amount of the 5^{th} harmonic current while it is equal to 3.8% for the source current i_s in case of the control scheme with STF. The LC filter is tuned at the 7^{th}-harmonic frequency and absorbs the voltage of the network at the fundamental frequency. Consequently, the dc voltage of the inverter v_{dc} can be reduced as low as 210V. The major aims of this paper were to simplify the classical feedback and feedforward control scheme by using of STFs and to validate the efficiency of the new control scheme and enables the hybrid filter to use low-voltage MOSFETs which are less expensive.

V. Conclusion

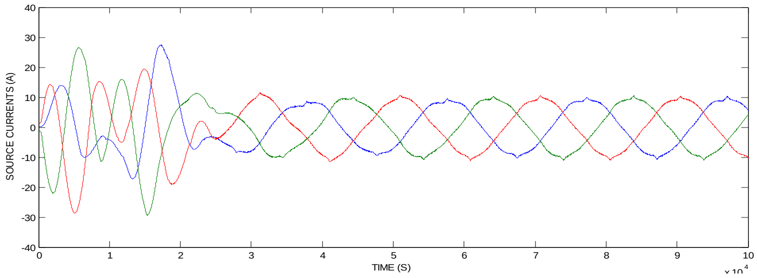
This paper validates by computer simulations the efficiency of three phase four wire hybrid filter (HAPF) with new control scheme based on STFs to suppress the harmonic currents produced by nonlinear loads. STFs have been introduced instead of high pass and low pass filters in the control loops. It can be used as frequency-selective filter for the compensation of high-power loads producing harmonic and interharmonic current distoration.

The new feedforward loop improved the filtering performances of the active filter and achieved high quality filtering. Simulation results demonstrate the major advantages ofusing STF in the control system. Morever, we can tune this STF at any frequency.

The simulation results have demonstrated and conforted the major advantages of using STF in the filter control. In conclusion, theoritical results demonstrate that the proposed control of (4-wire HAPF) is viable and effective in installation on an actual power system.



(a)



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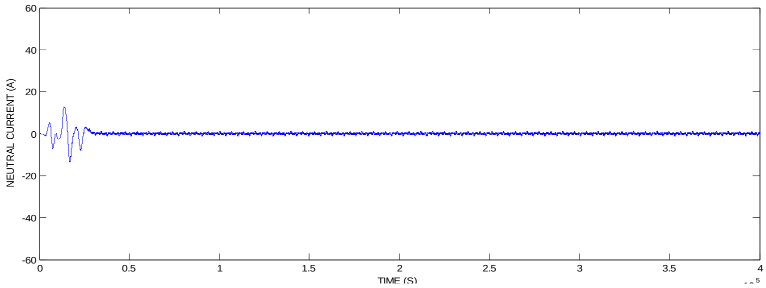

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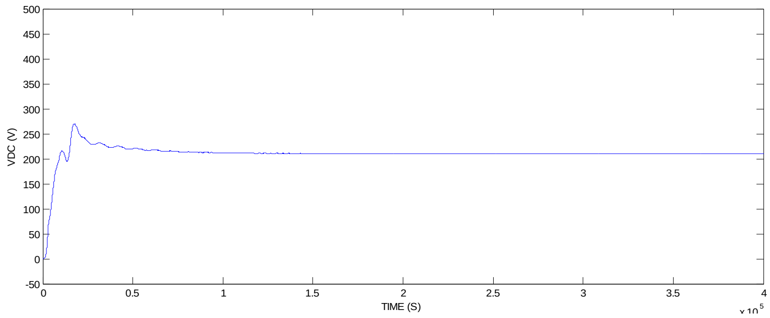

(d)

Figure 3. Simulation results of Hybrid Active Power Filter (HAPF):
(a): Three load currents i_{Labc} (A).
(b): Three source currents i_{Sabc} (A) after filtering.
(c): Neutral current i_N (A).
(d): DC-Bus voltageV_{DC} (V).

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